

OPERA neutrinos and superluminal helical motion

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Abstract

We pinpoint how a subatomic particle with non-zero mass may attain, in principle, velocities faster-than-light by travelling in helical motion in the limit of very large momentum. This is an educated guess by virtue of the MINOS and OPERA experiments on eventual superluminal propagation of neutrinos.

Keywords: Helical motion, Spiral, Kinematics and dynamics, Superluminal, Neutrinos

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Our main focus in this brief note is to pinpoint the possibility of having velocities faster-than-light ($v > c$) when considering helical motion for particles of non-zero mass m in the limit of very large momentum (mv). This is an educated guess to provide a side view regarding eventual superluminal neutrinos after MINOS [1] and OPERA [2] experiments. Alternative discussions include the assumption of tachyons [3, 4], neutrino dark energy [5], environmental fifth-force hypothesis [6], possible statistical mechanisms [7, 8] and Lorentz symmetry violations [9] to mention a few. The tiny influence of Coriolis effect in neutrino speed measurements between CERN and the Gran Sasso Lab is discussed in [10]. We introduce next our bold assumptions on the theme.

Elementary subatomic neutrinos are electrically neutral, weakly interacting, and have a small but non-zero mass. Being electrically neutral, they are able to pass through ordinary matter being 'affected' as shown below. To begin, we study first an energy-dependent speed model following discussions in [11, 12].

The total energy of fast moving objects satisfies the key Einstein equation $E = mc^2$. In terms of the momentum $p = mv = m_o v / \sqrt{1 - (v/c)^2}$, this relation can be rewritten as

$$E^2 = m_o^2 c^4 + c^2 p^2 \quad , \quad (1)$$

with m_o the object rest mass. If p is very large so that $m_o^2 c^4 \ll c^2 p^2$ (which means $v \gg c/\sqrt{2}$ or velocities $\sim 0.7c$ and greater), then the derivative of the above energy-momentum formula can be approximated as

$$dE \approx c \, dp = c \, d(mv) \quad . \quad (2)$$

This amount of energy (work) may be seen as transferred by a force F acting through a distance r relating Newton's second law of motion $F = dp/dt = (dp/dr)v$, with velocity $v = dr/dt$. Thus, it follows a 'new class' of Newtonian dynamics such that

$$F_N = \frac{dE}{dr} \approx \left(\frac{c}{v}\right) \frac{d}{dt}(mv) = mc \left(\frac{dv}{dr}\right) \quad . \quad (3)$$

Let us consider next that the direction of motion is constantly changing through a curved path (say, circular in 2D and helix in 3D), then the particle exerts an acceleration associated to the outward centrifugal force expressed as

$$F_c = -m \left(\frac{v^2}{r}\right) \quad . \quad (4)$$

In deriving this force, one approximates the *arc* of the travelling curved path as $S = r \theta$, with θ the angle measured with respect to the center of curvature and the radial direction. On the other hand, another path can similarly be drawn for the velocities such that $\Delta v = v \theta$. In the limit of small $\theta > 0$, or small gradients Δ (with $S \rightarrow \Delta S$), these two relations lead to

$$\frac{dv}{v} \approx \frac{dS}{r} \quad . \quad (5)$$

Therefore for the closed dynamical system to be in equilibrium the sum of forces $F_N + F_c \equiv 0$, so after some little algebra we have

$$\frac{v}{c} \approx \frac{r}{v} \left(\frac{dv}{dr} \right) = \frac{dS}{dr} \quad , \quad (6)$$

which implies

$$\frac{v}{c} \approx \theta \quad . \quad (7)$$

The special relativity derivation used in this approximation implies $\theta < 1$ to avoid infinite energies from $E = mc^2$, but it is still illustrative to pursue research MINOS and OPERA results.

The motion of neutrinos as described by the Dirac equation with a neutrino mass matrix [13], and a Lorentz scalar imaginary potential [14] (here considered to be negligible), also leads to an energy relation $cp_b = \sqrt{E^2 - (m_b c^2)^2}$ as in Eq.(1) and with b the flavor index. Thus, the simple above result suggests how a subatomic particle with non-zero mass may attain superluminal equilibrium velocities by travelling in helical motion in the limit of very large p and small $\theta > 1^\circ$ or 0.01745 *radians*.

In our approach, the ratio v/c may label the '*degree of spiralicity*' derived from an induced centrifugal force along a curved path, or it may denote a sort of 'averaged angle of incidence' between two helix points crossed in the least time in analogy with Fermat's principle. Our hope with this scenario is to shed new light for the propagation of superluminal neutrinos without the need to violate fundamental laws and well-established astrophysical observations [8]. As in [11], the local effect could be caused by a scalar field (here associated with the centrifugal force of Eq.(4)), which could be sourced by distorted regions of spacetime in the surrounding environment [15], at least for baseline distances of the order of the earth radius.

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